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ZOOLOGICAL PROGRESS[1]

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THE chase, the domestication of animals, and the practise of animal sacrifice in religious ceremonies were all customs of primitive man that led to an acquaintance with animal structure and habit long before human knowledge could be said to be organized. In the early steps of this organization, what we now know as zoology was a part of natural history, but in the specialization of modern times zoology has grown to the dignity of an independent science with numerous subsciences. In fact modern specialization has gone so far that concern has been frequently expressed lest the natural unity of science be entirely lost sight of; but, in sketching the outline of zoological progress, I hope to show you that, so far as zoology is concerned, this fear is unfounded.

Any outline of the course of zoological progress must be somewhat in the nature of an inventory of zoological possessions, and I can not do better in beginning this brief survey than to call your attention at once to the real materials of zoological research. These are the individual animals, which, as you well know, are not immensely diverse, but show certain agreements whereby they may be arranged in groups whose members have similarity of form and habit and show the remarkable trait of producing new individuals of like kind. These natural groups or species afford a basis for a descriptive inventory of the animal kingdom, and the attainment of such a complete description has been perhaps one of the most persistent motives to zoological work.

Progress in this undertaking is indicated by the increase in the number of species described at each successive period. Aristotle, who is usually regarded as the father of natural history and who lived in the fourth century B. C., mentioned in his zoological treatises about 480 kinds of animals. Linnæus, in the tenth edition of his "Systema Naturæ," published in 1758, described 4,378 species. Günther estimated that in 1830 a total of 73,588 species had been reached and that in 1881 the number had mounted to 311,653. Sharp placed the total in 1896 at 386,000, and, judging from the rate of increase in the vertebrates and echinoderms, the total number of described species at present must be approximately 500,000. From these estimates, which include only living species, it must be clear that in the twenty-two centuries between Aristotle and Linnæus the number of species known to the naturalist had increased only ten-fold, while in less than a century and a half after Linnæus the increase had been over a hundred-fold.

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[1] An address delivered at The College of the City of New York.

This enormous increase has been the result of two processes: the actual discovery of new forms in nature and the subdivision of what was originally regarded as one species into two or more species. The actual discovery of new forms implies the gradual exhaustion of nature and the conclusion of this process will come when exploration can yield no more new species. That the naturalist even of to-day is far from this goal is only too well known and can be illustrated by the following instances.

All of you doubtless have seen a delicate pearly shell, chambered somewhat like a miniature nautilus, but with its whorls open. This shell, which is known as the Spirula, is found commonly on the shores of the tropical oceans and may even reach our more northern coasts. It is extremely fragile and hence it can not last long on a surf-beaten shore. Nevertheless it is sometimes so abundant on tropical beaches as to form veritable windrows. Each shell is the life product of a single Spirula animal, which, so far as one can judge from the abundance of shells, must be a common inhabitant of the tropical seas. And yet, aside from fragments, the Spirula animals thus far obtained number only six. The first was collected in New Zealand and dissected by Sir Richard Owen. The second, for which no locality is known, was purchased by the British Museum from a dealer and dissected also by Owen. The third was collected near Port Jackson, Australia, and is now preserved in the Sydney Museum. The fourth was dredged near New Guinea by the "Challenger" and was studied by Huxley and Pelseneer. The fifth was taken by the dredge in the West Indies by the United States steamer "Blake," and the sixth was caught near Sumatra in a deep-sea net by the German expedition on the "Valdivia." If an animal as common as the Spirula must be, is known only by some six specimens, what a host of rare and undescribed species the ocean must contain.

Not only are the ocean basins treasure stores of undescribed species, but the land areas are also far from exhausted. It would seem fair to have presumed that of the terrestrial quadrupeds certainly all the larger and more striking species had been described, and yet, since the opening of the new century, a large cloven-hoofed mammal in general appearance somewhat between a donkey and a giraffe has been discovered in the Semliki forests of central Africa. This remarkable mammal was sought for in 1900, at first unsuccessfully, by Sir Harry Johnston, who finally succeeded in obtaining a skin and a skull from which the animal was described by Lankester in 1902. The natives call it okapi and report it by no means rare, and yet it remained almost to the present time without being known to science. But the naturalist is not obliged to search the deep sea or to journey to central Africa for new species. There is hardly an order of insects that could not be enriched with new forms by a season's collecting even within the limits of New York City, and it must therefore be evident that the half-million of species now described is only the beginning in the inventory of nature's stores.

In addition to the discovery of new species in nature, the process of splitting what was assumed by the older zoologists to be a valid species into two or more new ones has also considerably increased the number of described forms. This practise, though sometimes questionable, is at least illuminating, for it raises at once the fundamental question of what constitutes a species. In the days of Linnæus when special creation was more generally adhered to than now, it was comparatively easy to meet this question by the statement that a species is the aggregate of individuals represented by the originally created pair or stock and their descendants; but, with the acceptance of the evolutionary idea, this reply no longer sufficed. From the evolutionary standpoint every species has had a history and this history has been clearly one of change whereby the aggregate of more or less similar individuals at one time representing the species gave rise to the self-perpetuating stock whose more remote members evolved in one or more directions new features, so that the species either as a whole assumed new characteristics or split into two or more subordinate groups, each having its own special features and being destined eventually to become as well circumscribed from its next of kin as the original stock was at the outset. With this process in mind it is fair to expect that nature would be found to embrace many aggregates of individuals which would represent species at all steps of differentiation, and whether the individuals of a given aggregate had come to differ sufficiently among themselves to constitute a new species or not would depend entirely on the judgment of the naturalist who described them. It is thus clear that we can not expect any fundamental characteristic by which a new species can be definitely determined, for it is obvious that the transformation of species is a more or less continuous process in which the degree of separation whereby the new species will be established is somewhat arbitrarily determined by each describer. Hence the idea of species rests upon an artificial basis, and, if the describer's measure of specific difference diminishes with the progress of time, it is perfectly legitimate to subdivide previously described single species into smaller aggregates to be denominated new species.

Where this movement will lead to is not easy to foretell. It was hoped that the statistical methods of biometric work would make possible a solution of some of the difficulties in defining species, but, while these methods enable the investigator to discover and express differences between large groups of individuals vastly more accurately than the old methods of simple inspection and rough mental estimate did, they do not settle what characters or how many such shall be used in defining a species or what degree of difference must be arrived at before a given aggregate may be divided into two or more species. Nor does the recent proposition of de Vries come nearer to solving the problem. According to this investigator real species can be defined by a certain combination of characters which vary not in a continuous way but by leaps. These discontinuous variations constitute differences that may be as distinct as the differences between chemical elements; and any real or elementary species, as de Vries designates it, is distinguished by one or more of these elementary characters. Such elementary species, though open to variation, are cut off absolutely in their specific characters from other such species by a gulf that is never bridged by intermediate forms. Hence they ought to be as easily and distinctly describable as chemical compounds or even chemical elements. These elementary species, which have been for the most part heretofore ignored or passed over simply as races, etc., are the real units of systematic zoology and are much more numerous than the ordinary or Linnæan species. In fact, each Linnæan species probably consists of many elementary species and consequently the acceptance of this proposition would multiply the number of described species many times. But the difficulty with this proposal is to be found in the fact that an inspection of the so-called elementary characters shows them to be not so stable as de Vries assumed. In some characters, like coat colors, fixity is more or less realized; but in other features, particularly dimensional ones, such an amount of variation is shown that the resulting forms necessitate the same artificial methods of separation as those to which the older systematists were obliged to resort. From a radical standpoint there seems to be no escape from the view that a species is at best an imperfectly definable aggregate of more or less similar individuals and that this conception rests upon an artificial basis.

Although the idea of species must be admitted to be artificial rather than natural, its immense practical importance is not to be lost sight of; for, as a tool in the hands of the working zoologist, it is absolutely indispensable. Moreover, the arrangement of species into related groups and the development thereby of a system of classification has led to views on animal phylogeny of the utmost significance. That living animals range from the relatively simple unicellular protozoans to the immensely complex vertebrates suggests at once that the modern faunas include not only the latest products of animal evolution but many remnants of the remote past. This state of affairs is a continual temptation to picture the past history of the animal kingdom in terms of modern forms and to assume, for instance, that the protozoans of to-day are like the primitive protozoans from which the higher animals have been derived. This attitude leads to the discussion of the so-called affinities of the modern groups, a practise that in my opinion is open to the objection of attempting to make parents and grandparents out of brothers and sisters. How futile this practise is can be seen in such a group as the reptiles. You are doubtless aware that the modern reptiles are included in four orders: the chelonians, or turtles; the crocodilia; the rhynchocephalia, represented by a lizard-like reptile from New Zealand; and the squamata, or lizards and snakes. You are probably not so well aware that the class of reptiles also includes five other orders, all fossil, among which are to be found some of most specialized and prodigious land and water animals known. No possible consideration of the recent orders of reptiles would ever lead one to suspect the remarkable nature of these ancient forms, and the so-called affinities of the recent orders become meaningless in the light of the true ancestral relations as seen in the past history of the group as a whole. Tempting as the field of speculative phylogeny is, its results can never be of much value till they receive the endorsement of actual history as traced in fossil ancestry. In this connection I can not do better than quote a short passage from Huxley, who, as you well know, was an ardent student of fossil as well as living animals. In his essay on "The Advance of Science" he says:

> A classification which shall represent the process of ancestral evolution is, in fact, the end which the labors of the philosophical taxonomist must keep in view. But it is an end which cannot be attained until the progress of palæontology has given us far more insight than we yet possess into the historical facts of the case.

It is plain that the history of the animal kingdom is to be sought for not through ingenious speculations on the recent groups of animals, but by the persistent and patient exploration of the fossil-bearing rocks.

Although the study of animal genealogy, as outlined by fossil remains, is a relatively novel field, it has already yielded certain general results worthy of careful attention. It is customary at present to group all species of animals under some ten or twelve main divisions or phyla of the animal kingdom. These phyla have doubtless been evolved from some common group of animals in the remote past, and consequently, in tracing back their history as represented by fossil forms, it is not unreasonable to expect that their lines would gradually converge toward this common ancestral stock. In some instances, like the flat-worms, the phylum is known only through its modern representatives, and these representatives are of such consistency that it is not surprising that none of these animals have been preserved in the fossil state. But, aside from cases of this kind, all phyla that might be represented by fossils are, as a matter of fact, so represented; and the remarkable feature of this representation is that it does not show a convergence toward a common stock, but the phyla as such were as distinct in these early times as they are to-day. This state of affairs, which at first sight seems contrary to the evolutionary idea, is due in all probability to a universal destruction by extensive rock metamorphosis of the earliest of animal remains, and we are therefore probably correct in concluding that fossils at best give us only the later chapters in the evolution of the animal kingdom. Within a phylum the main lines of descent can sometimes be clearly discerned, but between phyla there are no absolutely certain connections, nor is there as a matter of fact a single completely extinct phylum known. These facts lead us to see that for an immensely long period the main divisions of the animal kingdom have been as they are at present and that the genetic connections of the phyla, which would be discernible with certainty only through their fossil remains, are, in consequence of the absence of these, probably absolutely and irrecoverably lost. Even the important suggestions that embryology has yielded as to the phylogenetic relations of the chief animal groups must remain forever hypotheses because of this irreparable blotting out of past records.

Although the systematic zoologist may look upon the animal kingdom as composed of imperfectly definable aggregates of individuals whose relations in the remote past are irretrievably lost but whose numbers are such as to occupy his labors for many years to come, his arrival at this conception has been over a course that has brought to view such a multitude of new prospects that the real extent of zoology is only now beginning to be dimly seen. These more recently acquired territories, which are now being cultivated with a vigor no less than that bestowed in past times almost exclusively on systematic zoology, must now be looked into. It is somewhat difficult for us to conceive of the state of mind of the zoologist of a century ago so far as his conception of the structure of animals is concerned. To him they consisted of organs composed of a variety of unrelated substances, such as muscle, membrane, bone, fat, blood, etc., which constituted the elementary materials of the animal body. It was therefore a great step forward when Schwann showed in 1839 that animals, like plants, were composed of structural units or cells whose physiological significance, as Brücke afterwards pointed out, entitled them to the name of elementary organisms. Many lower animals, belonging to what are now called the Protozoa, proved to be single cells, while the higher animals in all cases were found to be multicellular. The number of cells entering into the formation of the body of one of these higher animals is truly enormous. It is impossible to get reliable statements for these numbers in any single complex animal, but a recent careful estimate of the number of ganglion cells in the human cerebral cortex places the total at 9,200,000. As this enormous number of cells would occupy less than a cubic inch of space, one can form some rude conception of the prodigious number in the whole human body.

It is a remarkable fact that almost all cells, whether they are whole single animals or only parts of animals, are of small size. There seems to be something about the organization of a cell which ordinarily prevents it from enlarging much beyond microscopic proportions. The essential parts of a cell are its nucleus and the surrounding cytoplasm, and the continued activity of the cytoplasm is known to be dependent upon the presence and integrity of the nucleus. Such being the case it would seem as though the nucleus could administer to only a limited volume of cytoplasm and thus restricts the size of the cell. Apparently, however, this relation is one of volume and not of distance from the nucleus, for the cytoplasm of a ganglion cell may be drawn out into a most delicate nerve-fiber process that may reach half the length of the human body.

The arrangement of the cells in the body of a multicellular animal is not, as in most plants, of a more or less promiscuous kind, but conforms to certain fundamental principles. Among these probably the most important is one that depends upon the fact that animals assimilate solid food. To carry out this operation they possess almost universally a digestive cavity into which this solid food is carried and there rendered soluble. The only multicellular animals that do not possess a digestive cavity are certain parasites, like the tapeworm, whose modes of life are such as to make digestive organs superfluous. In the simpler multicellular forms, the coral animals, etc., the whole animal is sac-like in structure and may be briefly described as an animated stomach. Not only is this state characteristic of such primitive forms, but in the development of almost every multicellular animal known, the first organ to be formed is the digestive organ. This is brought about in that the cells, which are destined for the future animal's body, become arranged in the form of a two-layered sac in which the inner layer or entoderm bounds the digestive space and the outer one or ectoderm acts as a protective covering. Both layers develop a certain amount of muscular tissue and this is brought into action through external stimuli that from the nature of the case are received usually by the ectoderm. Hence this layer becomes the seat of those changes which in the higher animals eventually shape themselves in the sensory and nervous organization of these forms, while the entoderm is concerned with the digestive functions. Between these two layers there develops in all the higher multicellular animals a third layer, the mesoderm, which, as has been intimated, is primarily muscular in character but may also give rise to the internal skeleton, circulatory system, and other related sets of organs. Thus the body of a multicellular animal is composed of definite layers or masses of cells, chiefly three in number, with which special functions or modes of activity have become firmly associated.

Although these cell layers as such retain their limits in a most striking and clear way in the bodies of the higher animals, they must not be thought of as independent or in any sense isolated in their development. Their mutual relations are often of a most intimate kind and in the course of their development these relations tend rather to become more firmly consolidated than the reverse. This condition is well illustrated by the growth of the neuromuscular mechanism in animals, a growth that can be traced step by step through the multicellular forms till it finally shapes itself into the complex machinery whereby the animal reflexes are carried out.

The first step in this process is seen in the sponges, which in some respects are the simplest of the multicellular animals. As is well known, these animals are quite as sluggishly responsive to stimulation as plants are. A long and unsuccessful search for their nervous organs has ended in the belief that they possess no such structures. Some of their cells, particularly in the neighborhood of their numerous pores, are elongated or even fibrous and are apparently contractile enough to serve as a means of closing these openings. It is highly probable that these contractile cells, which may be regarded as primitive muscle cells, are brought into action by some stimulus directly applied to them, such as dissolved materials in the sea-water, etc. We are so accustomed to think of muscle as controlled by nerve that independent action of this kind seems wholly anomalous. And yet it must not be forgotten that muscle can be made to contract by the direct application of a stimulus and that even in the higher animals under natural conditions this may occur. Steinach has shown that when bright light is thrown on the eye of a fish or an amphibian the pupil will contract even after all vestiges of nervous connections have been destroyed, and he believes this to be due to the direct stimulation of the muscle fibers by light. This case supports the opinion that in sponges the contractile tissue responds to direct stimulation, and in my opinion the sponge represents the first step in the differentiation of the neuro-muscular mechanism, a step in which the primary and fundamental character of muscle is disclosed in that this is the only constituent present. This self-sufficiency of muscle is also made evident in the rhythmic beat of the embryonic chick heart before nervous differentiation has taken place.

In the sponges the primitive muscle cells lie either in the ectoderm or the subjacent mesoderm. In the coral animals, the jellyfishes, and their allies, the muscle cells occur in the deeper parts of the ectoderm and entoderm, a position where a forming mesoderm might be expected. It is usually stated that in the higher animals the muscles are derived from the mesoderm, and in individual development this is true, but from a phylogenetic standpoint I believe the reverse to be the case, namely, that the mesoderm has come from muscle and that the first step in the real origin of this layer is indicated in the migration of the muscular tissue of the cœlenterates or other like forms from the ectoderm or entoderm into the region between these two layers. This operation, which involves both layers in many of the lower animals, is usually limited in the higher forms to the entoderm, probably because this layer is the one which by reason of its proximity to the digestive cavity can best supply material for future growth. But, however this may be, it seems to me probable that the mesoderm has had its origin in the process of muscle formation, a process that is seen in its incipiency in the cœlenterates. That the mesoderm is also concerned with providing mechanical support for the animal is obvious, but in my opinion its contractile function is the primary one.

It cannot be stated with certainty at present that in the normal action of cœlenterate muscle this tissue is stimulated directly, though the investigations of Loeb on the jellyfish, Gonionemus, show beyond a doubt that such a method of stimulation is possible. It is, however, well established that in many jellyfishes muscle action is under the influence, if not the control, of nerves, and these cases represent, so to speak, the second step in the differentiation of a neuro-muscular mechanism. In such jellyfishes, groups of cells especially open to stimulation by light, pressure, etc., occur on the edge of the bell, and from these sense bodies nerve fibers pass to the muscular sheet on the under face of the bell. These sense bodies evidently act as triggers by which the muscular mechanism can be brought into action and in that way render it more delicately responsive than if it relied entirely upon direct stimulation. The relation of such a system may be described as that of a set of sense organs directly connected with a musculature, for there is nothing here that can be fairly described as a central nervous organ. As the sense organs are in the ectoderm and the muscles represent incipient mesoderm, it is obvious that the future development of these two layers will in this respect be most intimately bound together.

The last organ, in my opinion, to appear in this chain of development is the central nervous organ, the brain and its subordinate centers. This originated on the line of connection between the sense organ and the muscle, but rather from the sensory than the muscular end, as is shown by its anatomical relations in adult animals and by its invariable origin in the embryo from the ectoderm. It is scarcely recognizable in the simple multicellular animals and begins to be an obvious organ in such intermediate forms as the worms. Here it serves chiefly as a means of freer and more extended communication between the sense organs on the one hand and the musculature on the other, and thus lays the foundation for the marvelous development that it shows in the higher animals, where, as a storehouse of race and individual experience, its significance is unparalleled. The paramount importance of the brain in fact is so fully recognized that it is usual to treat the sense organs as appendages of it, but, if the view that I have advanced is correct, just the reverse is true; the sense organs of a bilaterally symmetrical animal are clustered at its anterior end not because the brain is there but because this is the end of the animal most likely to receive stimuli, and the brain is at this end because it has developed from this sensory equipment. The brain, in other words, is the appendage of the sense organs.

In tracing thus the growth of the three elements of the neuro-muscular mechanism, the muscle, sense organ, and brain, I have endeavored to keep before you their relations to those primitive organs, the ectodermic and entodermic cell layers, and to make clear to you how these cell layers come to be part and parcel of this growth. This subject might have been illustrated by any other set of organs than those concerned with the neuro-muscular mechanism; thus it is well known that the skeleton has been differentiated chiefly under the influence of the muscles, and that the digestive apparatus is as intimately associated with the differentiation of the circulatory organs as these are with the respiratory and excretory systems. But to discuss such relations even in a brief way would trespass too much on our present time, and I must therefore pass them by. Suffice it to say that in the main these relations constitute that province of zoology called by Goethe morphology, which includes the fundamental aspects of the form of adult and developing animals and which has been a field that for a century past has elicited the keenest interest from some of the most profound masters of zoology.

No one who has become deeply interested in morphological problems can have proceeded far without frequently meeting questions of a physiological nature. To answer these the simple observational methods of the past are insufficient, and it is necessary to resort to experimental procedure such as has been for a long time the practice of chemists and physicists. From this standpoint one enters what may be regarded as the most recent field of zoological research. Since the elementary substances of the animal body are the same as those of the inorganic world and since the stream of energy flowing through that body conforms in large measure to principles already discovered in the physical and chemical laboratories, it has been generally assumed that the life processes of an animal are nothing more than complex examples of physico-chemical interaction. This idea has proved most stimulating in its effect on research, but to what extent it will be found true can not at present be stated. It is quite possible that the chemist and physicist have as much of a fundamental nature to learn from living material as they have already gained from lifeless substance.

The paramount influence of material in animal reactions can not better be illustrated than in such processes as inheritance. It is well known to you how much more closely on the average offspring resemble their parents than they do other members of their own species, and you are familiar with the long persistence of certain family traits. These resemblances are explained by the fact that the offspring start from a certain amount of living substance contributed by each parent, but the powerfully determinative qualities of this substance are only to be appreciated in certain cases. It is well known that in human beings there are two classes of twins, identical twins and ordinary twins. The latter come from two separate eggs and may vary as much from each other as any two members of the same family. The former come from a single egg which by some accident has become separated into two parts. Identical twins are always of the same sex and are often so alike in features and actions that they are almost indistinguishable even to their near associates. Their close similarity, which may amount almost to identity, shows that the substance from which they both came has developed in a most rigidly uniform way and indicates that the development of ordinary twins, as well as of other individuals, is probably also closely limited from the beginning, but the degree of this limitation is not discoverable in these cases, for we have no basis of comparison. Since living material can thus duplicate itself in product, its significance in inheritance can not well be overestimated.

Not only may physical features be accurately inherited, but the capacity to perform various complex sets of actions may be transmitted with great precision. It is difficult if not impossible for us to state the exact source of many of our modes of actions. We inherit much and we learn much, and whether in a given complex act we are dealing with an inheritance or a new acquisition or a mixture is not always easy to state. With certain lower animals this question is perhaps more readily decided. Bees have the capacity of building a truly wonderful structure, the comb, which, because of economy of material and accuracy of workmanship, has long been an object of admiration. Is this complex activity inherited or learned by imitation? To answer this question, Kogevnikov reared some bees from a comb placed in an empty hive. After the bees had hatched and got their strength they proceeded without having seen other bees at work to make a comb that was as perfect as one made under ordinary circumstances. It might be objected that they had seen the comb from which they themselves had hatched, and this must be admitted to be so; but this fact is probably without significance, for they made perfectly typical queen cells the like of which they had never before seen. It is thus evident that not only structural peculiarities but highly complex activities can be inherited.

The means of this inheritance has already in a measure been made out. When a common protozoan, like Paramecium, reproduces, the parent body divides into approximate halves. Each of the two offspring receives not only a large portion of the parental substance but a certain number of cilia and other parts directly from the parent, and hence that the offspring should resemble the parent is not very surprising. When, however, reproduction in the higher multicellular animals is examined a somewhat different condition is discovered. Sexual reproduction is accomplished by means of a fertilized egg, which consists of a mass of cytoplasm chiefly from the maternal side, a centrosome from the paternal side, and usually an equal number of chromosomes from each side. As the offspring may resemble both father and mother, it follows that the substance that is the vehicle of inheritance is very probably the material of the chromosomes, the chromatin. This chromatin carries from parent to child not the vestige of an organ and is inconceivably small in amount. The human egg cell is approximately a sphere with a diameter of about 0.2 of a millimeter, and with a specific gravity about that of water; consequently its weight is about 0.004 of a milligram. The volume of the chromatin of a fertilized mouse egg, as measured for me by Mr. J. A. Long, is somewhat less than one-thousandth of the volume of the whole egg, and, assuming that this proportion holds for the human egg, and that its chromatin has about the same specific gravity as water, the weight of this chromatin would be about 0.000,004 of a milligram. Yet this mere trace of material can influence the adult substance of two identical twins to such an extent that their bodily configuration and actions are scarcely distinguishable. If we estimate their combined weights to be 130 kilograms, the chromatin of the egg from which they came can be said to have influenced in this profound way 32,500,000,000,000 times its original weight. Of course it must be borne in mind that the chromatin of the egg is living and that in the growth of the individual it assimilates and thereby increases in volume; the chromatin is not spread through the growing body in ever-increasing dilution. But, even granting this, its precision in the transmission of characteristics is certainly most remarkable; for when it is derived from a single source, as in identical twins, its effect upon the growth of the two individuals is to make them most strikingly alike. It is important to observe that the chromatin of at least certain male cells is composed very largely of nucleic acids, and that it is therefore very probable that the chemical composition and structure of these substances are intimately concerned with heredity. This discussion makes clear how extremely important certain materials are to the body and yet how impossible it is at this stage of scientific progress to frame any clear and consistent conception of the method by which these materials exert their influences.

If such relatively simple physiological questions as this concerning the material basis of heredity meet with difficulties such as I have pointed out, how vastly more intricate and perplexing must be the problem of the relation of the living materials of animals' bodies to their nervous and mental states. That such a relation exists is well recognized, but what this relation is will probably require many years even to outline.

It is in the direction of comparative physiology that the more important new advances in zoology are to be made. In my opinion zoology will meet with an expansion in this century quite as much as the study of electricity has in the last hundred years. When Franklin tried his hazardous experiment with lightning, no one suspected that he was dealing with a factor that could come to be of such paramount importance in every-day affairs as electricity has become, and it seems to me probable that the zoologist of to-day is working obscurely with problems that will eventually lead to revolutionary results. I have already pointed out the importance of certain minute quantities of material in inheritance, and the significance of this in animal breeding and in social problems must be evident. But in a thousand other ways the doings of animals are worthy of closest attention. Many of the most difficult problems that the human race has attacked have already found their solution among the lower animals. Secure aerial transportation, which is almost a dream with us, is an accomplished fact among many animals. Our own efforts are not so safe if they are more extensive than those of a flying fish. They are, however, by no means equal to those of a bat or an insect, and they are immensely inferior to those of a bird. Our systems of artificial illumination are regarded by us as one of the many evidences of advanced civilization and yet our best products are ridiculously poor compared with those of the lower animals. Gas or other such luminants yield at best something less than one per cent. light, the remainder of the energy being dissipated as waste heat, and our most successful means of illumination scarcely reach fifty per cent. of efficiency. The radiant energy of the luminous organ of a fire-fly is all light, and none is wasted as heat. Were the processes of this organ understood and made applicable to daily life, they would at once sweep out of existence every illuminating plant known. Such a revolution as this suggests awaits only the advance of zoological science, and, as I have said, this may be looked for in the near future. To my mind it affords one of the brightest outlooks for zoological investigation.

Thus far I have scarcely touched on what has been for so long a time the rallying word in biological work, evolution. But, if we knew the physiological workings of the animal body, especially in relation to inheritance, etc., evolution would be in large part understood and the lines of work that have just been recalled would be only examples of evolutionary processes. The most promising recent change in the study of evolution, a change which we owe largely to de Vries, is the discovery that evolution as now understood is probably going on before our eyes and at a measurable rate; hence it is open to observational and experimental treatment and we may expect renewed and rapid growth in the near future for this line of work.

Many of the unexplored regions touched upon in this survey are of such magnitude that few can hope to be their conquerors, but all may aid in preparing the way. In invading these new regions former methods and means will be sure to be found insufficient; the help of kindred sciences, such as physics and chemistry, must be called upon. This appears to be a sufficient answer to those who thought that they saw in the subdivision of zoology and of other sciences a step away from the true unity of scientific endeavor.